International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 6, Dec 2018, 579-588

THE MODELLING OF CONTACT FORCE OF THE ROBOT GRIPPER FOR DEFORMABLE OBJECT USING FINITE ELEMENTS METHOD

S. NATARAJAN[1], A. JEGAN[2] & R. VIVEKANANTHAN[3]

[1]*Department of Mechanical Engineering, Vinayaka Mission's Kirupananda Variyar Engineering College, Vinayaka Mission's Research Foundation (Deemed to be University) Salem, Tamil Nadu, India*

[2]*Department of Mechanical Engineering, Sona College of Technology, Salem, Tamil Nadu, India*

[3]*Department of Mechanical Engineering, Government College of Engineering, Salem, Tamil Nadu, India*

ABSTRACT

Designing of robot gripper is an emerging research area due to its applicability in automation, especially for handling of soft objects. This paper presents a mathematical model of robot grippers for soft material. The grippers are capable of grasping soft objects and they require minimum contact force to prevent damage or deformation of the objects. The contact force on the gripping surface depends upon the shape of the changeable contact area between the gripper surface and the surface of the object because of the changing contact region. Using ANSYS software, these deformations are simulated, relating to a flat gripper and soft gripped materials using elasticity theory. Simulation results are analyzed. These results show that contact force depends on contact pressure and contact area of the deformed surface. This model produced the best results when contact force included in the model. The proposed approach is needed for precise estimation of contact forces, which is needed in real time feedback control system to regulate the contact force for handling soft objects and prevent slip based on force control approaches.

Keywords: *Underactuated Robot, Gripper Design, Contact Force, Soft Material & Stable Gripping*

Received: Sep 19, 2018; **Accepted:** Oct 09, 2018; **Published:** Nov 27, 2018; **Paper Id.:** IJMPERDDEC201861

Original Article

1. INTRODUCTION

Robots are now expected to perform in a largely autonomous manner in unstructured dynamic and uncertain environments. In the context of real time system, dynamic simulation is required for accurate modelling of contact between the surfaces of an object and gripper. Whether the gripper can achieve stable gripping or not it depends on the contact position, contact force, torque and constraints of contact points. The analysis of contact between the gripper and the workpiece is necessary for the designing of a gripper. Deformable object or motion of the object within the gripper sometimes leads slip (Jazi *et al,* 2008). This will result in a positioning error of the object. A good measuring quality of the grasp is taken in two ways. One is planning of a manipulation sequence that allows the optimization of the positioning of the gripper on the object to be grasped and the second is grasping forces that provide execution of a grasping task.

Recently, researchers have proposed an effective formulation for dynamic modelling of gripping systems. (Bicchi *et al*, **2000)** focused on issues that are to the mechanics of grasping and the finger object contact interactions. (Yoshikawa *and* Nagai, 2002) presented an overview of the recent advances in force control of robot manipulators. A force control algorithm is followed by either explicit or implicit force control. In explicit force control, the forces and torques between gripper and objects are compared with the desired values of the contact

forces. This was done by computing gripper accelerations, contact forces, motion and the new state of the deformable regions in the contact surfaces. (Datta *et al,* 2015) worked on a multi objective optimization to find the dimensions of links and the joint angle of a robot gripper which is nonlinear and multimodal problem (Barkat *et al*, 2009).

Hertzian pressure distribution was assumed for the normal contact load over a contact area. The tangential forces in both the sliding and lateral directions were considered and were assumed to be proportional to the Hertzian pressure. (Spanjer *et al,* 2012) used variable transmission ratio by the knowledge of shear force and the controlled contact force to maintain a constant ratio between these two to predict the equilibrium positions of the finger and the object. (Varkonyi, **2015)** used deformable contact models and demonstrated that the frictional equilibrium of a system of rigid bodies is a local minima of their potential energy.

Practically grasping of soft material requires a gripper to exert minimum contact force and to maintain grasping with optimal time and minimal overshoot. (Kim, **2001)** computed contact points and forces to grasp and to generate feasible stable grasp. The General robot grasp planner was designed to provide grasp direction while the robot decides the level details of contact point location and grasp pose (Goins *et al*, 2016). Hao Dang *and* Allen **(2014)** presented an algorithm based on tactile experience based hand adjustment to synthesize a hand adjustment and optimize the hand pose to achieve a stable grasp.

(Dalibor *et al*, 2013) developed an adaptive neuro-fuzzy inference system to apply desired force to an unknown environment by adjusting the force control using a fuzzy vector method. Adaptive control is another technique used to regulate the contact force on an unknown and the changing environment (Nogueira *et al,* 2013). Adaptive fuzzy control scheme adjusts the membership functions of the fuzzy controller by learning the environmental parameters and adapting the control mechanism. Neural Network based methodologies compensate the effects of non-modelled phenomena. (Lin *et al,* 2007) had done experiments on the manipulator in contact with a fragile environment. He used persistently exciting reference signal to measure environment parameters when the environment is continuously changing. (Zhang *et al,* 2013) extracted multiple image features of the gripper and the ring object to estimate the relative positions between the gripper and the ring object.

Grasping errors occurred due to variations in physical, mechanical and surface properties of the soft materials. It is important to minimize the necessary gripping force to avoid unnecessary stress and deformation on both the object and the robotic gripper (Zaki, 2010) and **(**Garg *and* Dutta, 2006). A It is, therefore, necessary to establish a relationship between the load, displacement, and geometry of the gripper and the behaviour of the materials being handled in order to achieve an optimal gripping process (Smith, 1999). The objective of this research is to develop a model for an underactuated gripper with a stable grasp which can be established without moving the object. This contact model should make it possible to grasp soft products onto a flat surface without damaging the product.

2. FINITE ELEMENT ANALYSIS

The dynamic force of the robot gripper is limited by gripping force and its positions. This force can be obtained by the derivation of contact force. The grasping strength of the gripper is improved by its mechanical strength. In order to improve the mechanical strength of the gripper, an analysis has been done on contact force between gripper and object. Finite Element Method (FEM) is used to analyse dynamic force on gripper in which the soft materials are taken into account. Defining of preliminary data such as model of the gripper, its properties, applied force and boundary conditions

are very difficult to carry out the analysis in ANSYS. Modelling and simulation has been undertaken in ANSYS finite element package based on the geometry as shown in Fig. 1. In this simulation, solid elements were used for the entire model. The contact was created by using ANSYS software, where the object is the contact element and the gripper is the target element by selecting CONTAC 174 and TARGE 170 for 3D contact model. For this grasp, the contact locations are made at different locations on the surfaces which are typical when grasping at centroid and above and below the centroid of the surface. The applied load is 60 N.

The force applied on the contact points. The positions of contact points on the surface are different and deformed shape of the objects are determined. The results are tabulated for different positions separately. The applied force produces complex deformations. The contact stresses are obtained for determining contact force due to the reaction forces exerted on the object surface during grasping the object. The contact force of the grippers is determined by contact stress and contact area. The distribution of contact stress is changed for different positions. Contact stress components and deformation of the surface depend on the applied external load and the behaviour of the material. The resultant contact force depends upon the shape of the contact between the grippers and the surface of the object.

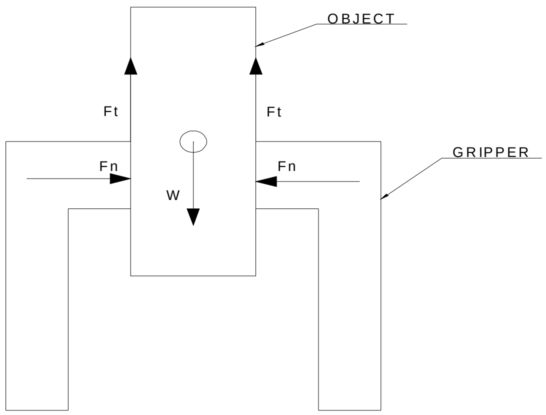


Figure 1: The Configuration of the Robot Gripper Mechanism

The tangential and the normal forces in the contact plane can be calculated by integrating the contact pressures on contact surfaces of the X and Y axes for the tangential forces and Z axis for the normal force.

$$F_X = \iint p_x \, dxdy \quad (1)$$

$$F_Y = \iint p_y \, dxdy \quad (2)$$

$$F_Y = \iint p_z \, dxdy \quad (3)$$

At the contact point, the resultant contact force can be de-segmented into normal and tangential components. The tangential force is placed F_Y on the Y axis and F_X on the X axis and F_Z be the normal component of contact force based on the equations (1), (2) and (3).

Contact force = $\sigma_C * A_c$ (4)

Where, A_c-contact area, σ_{C}-contact stress

Contact area= b*h (5)

Where, b- width of the contact area, h- height of the contact area

then moment, $M_Z = \iint (xp_y - yp_x)dxdy$ (6)

The contact force at the left side and right side of the object are equal and opposite because of the parallelism of the gripped faces. The contact force Fz

$$2F_z = \iint p_z\, dxdy + \iint p_z\, dxdy \tag{7}$$

As a result, contact force leads not only to a resultant force applied to the center of the contact area, but also to a non-vanishing moment about the normal axis through the center of the contact area. This moment, M_Z is the function of the contact force and the position of contact. Since M_Z rotates object, it should be added to the equation (6) using a sign function. Increasing of moment will cause the object to be twisted out of the grip. The contact stress distribution is measured from the ANSYS analysis. The strain at the left side or right side of the object can be derived by substituting the equation (6) into the strain equation (8).

strain, $e = {M_x}/{EZ}$ (8)

Where, E- Youngs modulus of the material

Z- Moment of inertia

3. CONTACT FORCE MODELING

Contact models represent the effects of the forces exerted on the object surface. Figure 2 shows a simple model for contact force calculation. It is assumed that the gripper is rigid and the object is deformable. In most of the cases, simulations are solved using rigid contacts which cannot model the deformation of an object. A model has been created for soft material contact. Therefore, the local deformation is taken into account for modelling of soft materials. In practice, uniform pressure is not sufficient to satisfy the equilibrium conditions. Non uniform pressure is developed for a precise form of soft material.

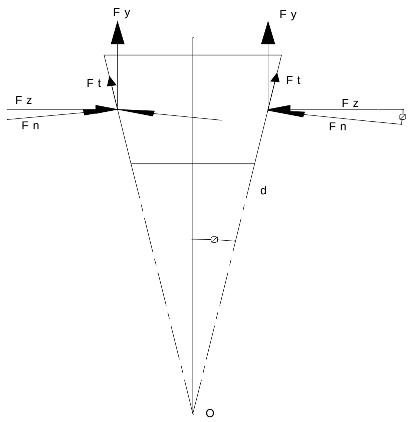


Figure 2: Forces on the Two Finger Gripper Used in this Work

The actuator force can be transmitted through links according to the gripper and it depends upon the position and angle at which the links are positioned. The applied force is completely defined with both magnitude and directions. The

contact plane is rectangular and the contact stress varied linearly as shown in Fig.3. On each contact point, the resultant force, F can be written as:

$$F = F_t + F_n \tag{9}$$

Where F_n is the normal force produced by the soft contact and F_t is the tangential force represented by friction. In case of rigid gripper, the contact patch between gripper and object is rectangular and that the normal force produces an uniform pressure distribution along the tangential contact plane which produces resistance to motion. The soft material contact can transmit both a normal force and a tangential force and also allows the gripper to exert a pure torsional moment about the common normal at the point of contact. A contact force model is created and it enables the calculation of surface forces as well as the holding torque around the contact surface. If the following condition is not satisfied then slipping may occur according to the equation7

$$F_x^{\ 2} + F_y^{\ 2} \leq \mu^2 F_z^{\ 2} \tag{10}$$

The distribution of the contact forces varies while the gripper is moving, because such distribution depends on the position of the contact points of the objects. The contact forces are estimated at the equilibrium of the gripper and object. The contact force is varied linearly across the contact area as shown in Figure 3.

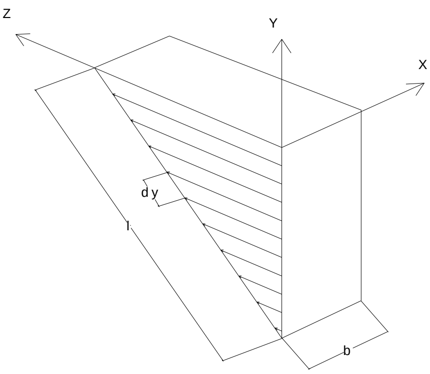


Figure 3: Contact Surface Model of the Gripping

It is assumed that the deformation in X axis of the object is zero, so that the contact force Fx= 0 and Fz is expressed as the function of contact pressure. It is assumed that the contact stress in Y direction is varied. The resultant stress in Y direction is

$$\mathrm{F_Y} = \iint \mathrm{p_y}\, \mathrm{dxdy}$$

$$\mathrm{F_Y} = \iint \mathrm{p_y}\, \mathrm{bdy}$$

If y=0 then $\mathrm{p_z} = 0$

y=l then $\mathrm{p_z} = \mathrm{p_{max}}$

$$\mathrm{F_Y} = \frac{\mathrm{lb}}{2}\, \mathrm{P_{max}} \tag{11}$$

Where, p = load per unit length

Contact area= b*l

From the equation (11), the contact force depends on the deformation area and the function of the distance from the contact point. The distance *d* from the tangent plane of the object surface at the contact point with respect to coordinate frame is considered. The center point of the contact area P_i is defined as a projection of the center of the gripper the mean contact plane. It depends only on the distance *d* and the contact normal: $\vec{d}\,\vec{n}_i$

Obviously, the deformation makes an angle θ and de-segmented the tangential force. The condition for the slip is

$$(F_x \cos\theta)^2 + (F_y \sin\theta)^2 \leq \mu^2 F_z{}^2 \quad (12)$$

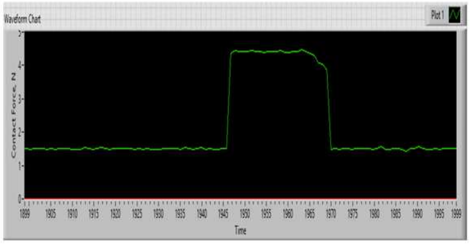
4. EXPERIMENTAL SETUP

In this section, contact conditions are planned and the contact forces are obtained at three different positions of contacts experimentally in a more realistic manner. Figure 4 shows the experimental setup of a gripper that is comprised of servo controller for motion of the manipulators and a strain gauge sensor interfaced with LABVIEW software for measuring contact force.

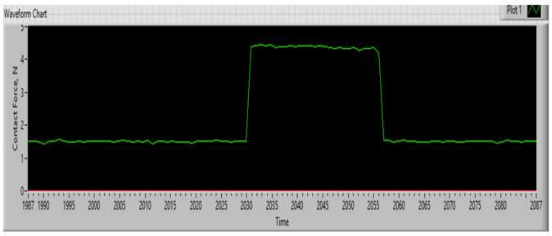
Figure 4: Two Finger Gripper 6-Axis Robot with Strain Gauge Sensor

The experimental contact forces are found and plotted. Figure 5 shows a contact force distribution, which is caused by an applied force with the 6-axis robot setup.

(a) Position above the Centroid



(b) at the Centroid



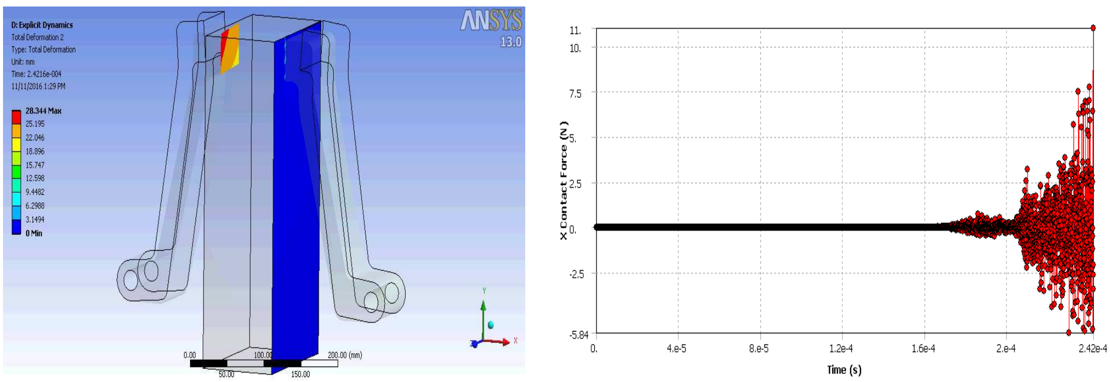
(c) Position below the Centroid

Figure 5: Measured Grasping Forces with Different Positions

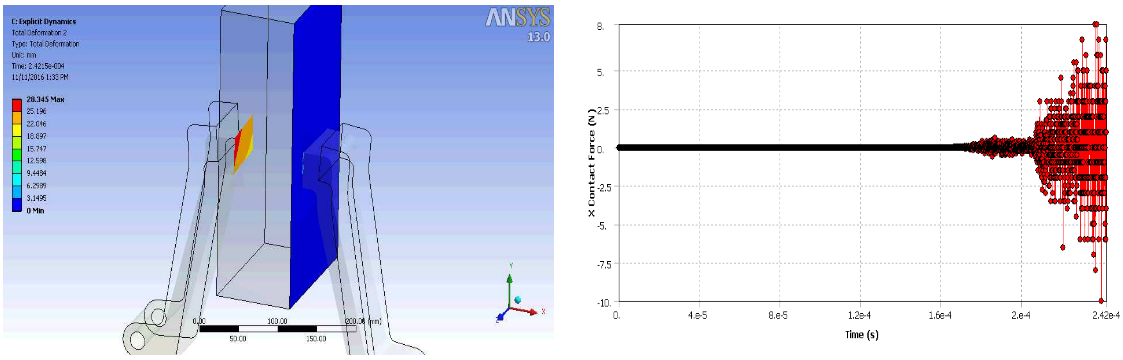
A quantitative measurement of the contact force is obtained using a strain gauge sensor with deformable ABS polymer as the contact medium. This would be complicated due to the non-linearity and hysteresis response of the material by applying more force. In our experiments, the contact force of the ABS polymer was found to be proportional to the resultant with respect to time. The magnitude of the contact force has come from strain gauge and was recorded by the LABVIEW software system. To compare the grasping capabilities of the gripper, the grasping force is more than the position at centre and above the centroid.

5. RESULTS AND DISCUSSIONS

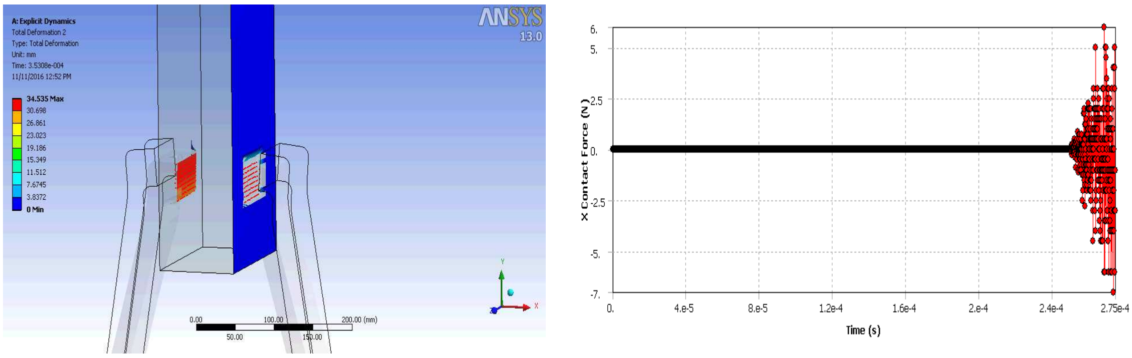
The manipulated control action is needed to correct errors which may be determined in the control system. Large manipulation control may cause instability due to un-modelled dynamics. Dynamic model with contact force gives more accurate results in applications where deformation plays an important role. In this case, calculating contact stress and holding torque around the contact patch are taken into account. The status of the sliding and its rotation of the gripper on the object can be easily verified by the equation (10). If the contact force produces a clockwise moment around the equilibrium point, then the gripper will rotate clockwise and vice versa.



(a) Position above the Centroid



(b) at the Centroid



(c) Position below the Centroid

Figure 6: ANSYS Results of the Contact Force Based on the Positions

The result of finite element analysis is introduced to make a model and to find suitable relationships between the load, displacement and geometry of the gripper. The simulated contact force F is plotted in Figure 6. The result shows that the gripper with deformation plane intends to reduce the grasping force with a same applied force F_a = 30 N. The gripper with deformable plane produces 25% of contact force more at position above centroid and less at below centroid compared to the position at the centre of the object.

The moment of contact force on the gripper will cause rotation around its axis, which moves the object away from its horizontal axis and sliding of contact points. The sliding would not stop until resultant friction force F and contact force gets equilibrium. The system approaches equilibrium as illustrated in Figure 2. The Figure 5 indicates that the resultant contact forces are 20 N, 18.57 N and 17.85 N position above the centroid, at the centroid and position below the centroid respectively. Here the deformable plane produces 7.15% of contact force loss from the end of the tip. Fortunately, this contact force is still below the yield stress of the object material. The results indicate that the loss of contact force is in response of the deformation area and contact positions. The increasing moment has changed the contact force. While analysing the results it is clear that for the same contact area rectangular contacts develop better contact force away from the bottom end. Therefore, the gripper can be designed with contact locations above the centroid.

6. CONCLUSIONS

The dynamic control strategy was investigated with the contact model for stable gripping according to the contact forces between the gripper and work piece. Contact force and contact stress could be easily estimated by ANSYS analysis in the gripper design. Designing a 3D model of contact geometry is to estimate gripper contact forces, according to the gripper contact position. Simulations were done on ANSYS software and the results were obtained. To improve the

gripping stability, the friction between grippers and their contact force should be increased properly. The above analyses provide a good foundation for the optimal design of the gripper structure and the control system design of manipulators.

An attempt is made to study the correlation between contact force and torque with respect to their contact position. Gripper contact force is estimated. The slip influenced on the contact force magnitude.

The experiments on a gripper is conducted and successfully demonstrated that the method works in practice. A precision grasp depends on the position of the contact on the object and geometry parameters of the gripper and object. The contact force is predicted by experimentation. Experimental and theoretical force results showed that optimum contact force obtained and this may be improved by the position above the centroid.

REFERENCES

1. *Shahram Hadian Jazi, Mehdi Keshmiri and Farid Sheikholeslam, 'Dynamic Analysis and Control Synthesis of Grasping and Slippage of an Object Manipulated by a Robot', Advanced Robotics, 22, 2008, 1559-1584.*
2. *Antonio Bicchi and Vijay Kumar, 'Robotic Grasping and Contact: A Review', IEEE international conference on robotics and automation, vol.1, March 2000, 348-353*
3. *Yoshikawa.T and Nagai.K, ' Manipulating and grasping forces in manipulation by multifingered robot hands', IEEE Transactions on Robotics, vol.7, issue 1, 2002, 67-77.*
4. *Rituparna Datta, Shikhar Pradhan, and Bishakh Bhattacharya, 'Analysis and Design Optimization of a Robotic Gripper Using Multiobjective Genetic Algorithm', IEEE Transactions On Systems, Man, and Cybernetics Systems, 46(1), 2015, 16-26.*
5. *B. Barkat, S. Zeghloul, and J. P. Gazeau, 'Optimization of grasping forces in handling of brittle objects', Robotics and Autonomous Systems, vol. 57, No. 4, 2009, 460–468. 444*
6. *Stefan A.J. Spanjer, Ravi Balasubramanian, Aaron M. Dollar and Just L.Herder, 'Underactuated Gripper that is able to convert from Precision to Power Grasp by a Variable Transmission Ratio', ASME/IEEE International conferenece on reconfigurable mechanisms and robots, Tianjin, China, 2012, 669-679.*
7. *Várkonyi, Péter L. "On the stability of rigid multibody systems with applications to robotic grasping and locomotion." Journal of Mechanisms and Robotics 7, no. 4 (2015): 041012.*
8. *Kumar, P. A., & Narayan, Y. S. Design of a Quadruped Robot and its Inverse Kinematics.*
9. *Kim G. Design of Two-Axis Force Sensor for Robot's Finger. Trans. Control, Autom. Syst. Eng., Korea. 2001 Mar;3(1):66-70.*
10. *Alex K. Goins, Ryan Carpenter, Weng-Keen Wong. Ravi Balasubramanian1, 'Implementation of a Gaussian process-based machine learning grasp predictor', Autonomous Robot, 40, 2016, 687–699*
11. *Hao Dang and Peter K. Allen, 'Stable grasping under pose uncertainty using tactile feedback', Autonomous Robot, 36, 2014, 309–330.*
12. *Dalibor Petkovic, Nenad D. Pavlovic, Zarko C ojbasic, Nenad T. Pavlovic, 'Adaptive neuro fuzzy estimation of underactuated robotic gripper contact forces', Expert Systems with Applications, 40, 2013, 281-286.*
13. *Samuel L.Nogueira, Tatiana F.P.A.T. Pazelli, Adriano A.G. Siqueira and Marco H.Terra, 'Experimental Investigation on Adaptive Robust Controller Designs Applied to Constrained Manipulators', Sensors, 13, 2013, 5181-5204*
14. *Hua Lin, Paul M. Taylor, Steve J. Bull, 'Modelling of contact deformation for a pinch gripper in automated material handling', Mathematical and Computer Modelling, 46, 2007, 1453-1467.*

15. *Juan Zhang De Xu Zheng-Tao Zhang Wen-Sheng Zhang, 'Position/Force Hybrid Control System for High Precision Aligning of Small Gripper to Ring Object', International Journal of Automation and Computing, 10(4), 2013, 360-367.*
16. *M. Zaki, O. A. Mahgoub, A.M. El-Shafei, A. M. Soliman, Design and Implementation of Efficient Intelligent Robotic Gripper, WSEAS Transactions on systems, vol.9, Issue 11, 2010, 1130-1142.*
17. *Garg S, Dutta A. 'Grasping and manipulation of deformable objects based on internal force requirements', International Journal of Advanced Robotic Systems, 3(2), 2006, 107-114.*
18. *Gordon Smith, Eric Lee, Ken Goldberg, Karl Bohringer and John Craig, 'Computing Parallel-Jaw Grips', IEEE International Conference on Robotics and Automation, Detroit, MI, May 10-15, 1999, 1-7.*